Colour centres involved in radiation-induced losses of erbium-doped aluminosilicate optical fibres

Yasmine Mebrouk, Franck Mady, Jean-Bernard Duchez, Mourad Benabdesselam

Colour centres involved in radiation-induced losses of erbium-doped aluminosilicate optical fibres

Yasmine MEBROUK, Franck MADY, Jean-Bernard DUCHEZ and Mourad BENABDESSELAM

Université Nice -Sophia Antipolis, CNRS, Laboratoire de la Physique de la Matière Condensée, UMR 7336, 06300 Nice, France

Preference: Oral, Radiation effects

ABSTRACT

In this paper we report results of thermal anneal study to investigate the correlation between radiation effects on erbium-doped aluminosilicate fibres made by MCVD and the increase of the optical absorption of AlE' and NBOHC centres. Thermolumiscence and absorption measurements in the UV-Visible and NIR domains clearly show that Er^{3+} ions are involved in this optical absorption behaviour.

Keywords: optical fibres, thermoluminescence, silica, radiation.

1 INTRODUCTION

Optical properties of erbium-doped silica-based fibres are significantly affected by ionizing irradiation [1]. Radiation leads to the conversion of some native defects into colour centres (CC) by electron or hole trapping [2] and gives rise to the so-called radiation-induced absorption (RIA). Understanding the RIA development under irradiation is the main key for assessing its resistance in harsh environments. This paper shows that, additionally to the RIA, the gain of erbium-doped amplifiers is damaged by the loss in Er^{3+} ions under irradiation. By the mean of thermal annealing experiments, we correlate the recovery of Er^{3+} ions to the well-known silica defects, especially the non-bridging oxygen hole centre (NBOHC) absorbing at 2 eV [3] and AlE' centre with its absorption band at 4 eV [4].

2 EXPERIMENTAL

Irradiations were carried out with a 45 kV X ray tube. Absorption measurements were performed by means of a PerkinElmer Lambda 1050 spectrophotometer. Both irradiations and absorption measurements have been carried out at room temperature (RT). The RIA is calculated as the difference between the post- and pre-irradiation absorption coefficient spectra (in mm^{-1}). TSL measurements were performed with a Harshaw TLD 3500 reader. This technique is a powerful tool to study the thermal relaxation processes, especially in rare earth doped fibres [5]. TSL consists of photons emitted upon radiative recombination of 'detrapped' carriers with carriers of opposite polarity on reduced/oxidized centres (recombination centres). After radiation exposure, samples are heated up linearly (2 °C s^{-1}) from RT up to 600 °C and carriers are thermally released from traps of increasing depths. The TSL is plotted as a function of temperature to give 'glow curves' that reflect the energy distribution of trapped states generated by irradiation. Glow curves exhibit peaks. Each trapping level gives rise to a single peak (the deeper the trap, the higher the peak temperature). TSL spectra acquired at any temperature with an optical multi-channel analyzer allow the identification of photoionized luminescent centres. Samples are preform discs with 0.5 mm core radius and 1 mm thick fabricated in our laboratory by modified chemical vapour deposition (MCVD) and solution doping. Undoped silica (SiO_2), aluminum doped silica (SiO_2:Al), Er-doped aluminosilicate (SiO_2:Al,Er) and Er-doped silica (SiO_2:Er) samples are considered in this study.

3 RESULTS

Normalized TSL glow curves obtained after X irradiation are shown in Fig. 1. They present three main peaks between 100 and 150 °C (peak 1), in the 200-250 °C range (peak 2) and between 350 and 450 °C (peak 3). For the SiO_2:Er, SiO_2 and SiO_2:Al samples, the second peak is not intense but it contributes to the broadening of the 100 °C first peak. None of the TSL peak can be attributed specifically to Al or Er, but the Al-Er co-doping apparently enhances the third peak (near 400 °C). TSL spectra from Er-containing samples always consist of the Er^{3+} luminescence lines. It is the case of the SiO_2:Er perform, for which the visible TSL spectrum is shown in the inset of Fig. 1. This luminescence is observed throughout the temperature range (RT-600 °C). The thermal relaxation therefore involves the recombination of detrapped carriers to form Er^{3+} ions. Accordingly, the irradiation must be responsible for a valence change in Er^{3+} ions (presumably forming Er^{2+} ions and hence trapped holes). As a result, Er^{3+} ions are involved in the darkening and bleaching processes. This is a novel statement, since the Er implication was dismissed to date [6]. Therefore the

amplifier performance will be dropped not only due to the colour centres (darkening) absorbing signal and pump, and so damaging the gain, but also because of the loss in Er^{3+} ions, which will reinforce the gain degradation.

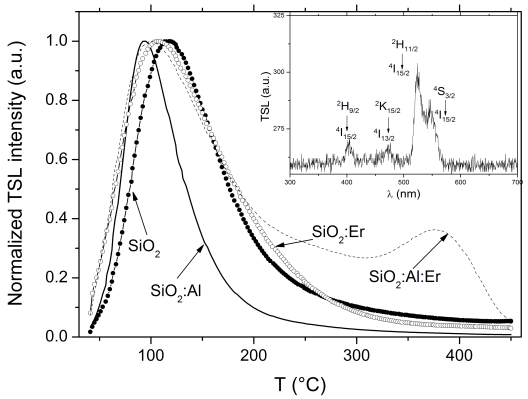

Fig. 1. Normalized thermoluminescence intensity after X rays exposure. Inset: Spectrum analysis of erbium doped samples TSL

Core-absorption spectra for the SiO_2:Al,Er sample is plotted in Fig. 2. The related RIA (in mm^{-1}) is shown in inset. Dashed curves correspond to absorption after thermal bleaching from RT up to 600 °C, by steps of 50° (T_{stop} = 50, 100, …, 600 °C). The absorption returns down to its initial value as T_{stop} is increased, thus showing that the darkening process is fully reversible. The annealing is done at the same heating rate as TSL measurements (2 °C/s) to allow the comparison of the T_{stop} values with the TSL temperature scale. Er^{3+} ground state absorption transitions to $^2G_{11/2}$ and $^4S_{3/2}$ levels are located at 378 and 521 nm respectively.

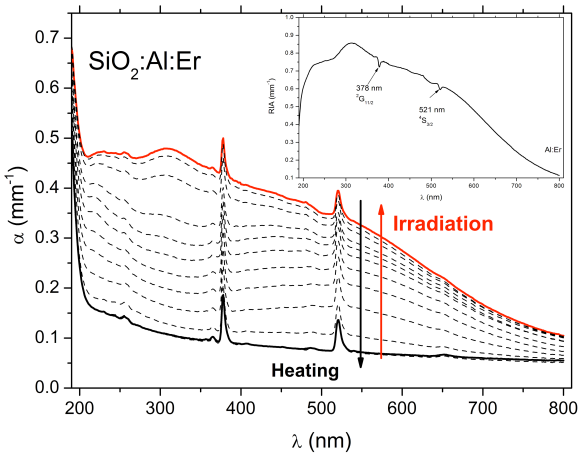

Fig. 2. Core-absorption spectra before (black) and after (red) X-ray irradiation for the Al-Er-doped preform. Inset: radiation induced absorption

We calculated the optical intensity OI (OI = FWHM · maximum intensity) of each band for pristine, irradiated and all intermediate T_{stop} spectra. The results are shown on the upper part of Fig. 3. OI of Er^{3+} absorption bands in the UV-visible range decreases by more than 20% after irradiation and then recovers with increasing T_{stop}. Measurements done in the NIR range (not presented here) show the same reduction in the Er^{3+} absorption around 1530 nm. The Er^{3+} density is well reduced by irradiation and recovered by recombination under thermal stimulation. For a 10 m long fibre initially doped with 10^{19} cm^{-3} Er^{3+} ions and a 300 mW pump input power, a 20% decrease in the Er^{3+} ion density results in a > 50% gain drop at 1530 nm (out of RIA). The lower part of Fig. 3 displays the recovery peaks, i.e. derivatives of the upper part plots (in % of the total RIA at each wavelength). These recovery peaks clearly correlates to the TSL curve, showing the Er^{3+} ions partially recover at each TSL peak, i.e. when carriers are progressively released from deeper TSL trap. In the inset of Fig. 3 we plotted (in % of the total RIA) the recovery peaks at 2 (NBOHC) and 4 eV (AlE'). NBOHC mainly recover around 400°C. Hence the third TSL peak can be related to NBOHC relaxation. AlE' centres recover at 150°C and rather correlate to the first glow peak (100-150 °C). Since NBOHC and AlE' are trapped-hole centres, it appears that TSL peaks rather correspond to holes release. This finding supports the proposal that Er^{2+} ions are formed together with trapped holes.

Behaviours of the other RIA bands and their involvement in the darkening/bleaching mechanisms will be reported at the conference.

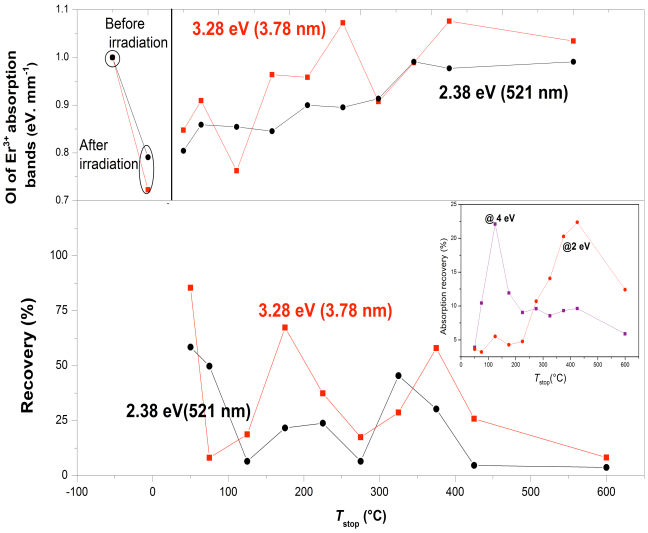

Fig. 3: Up : OIs of 521 nm and 378 nm Er^{3+} ion absorption bands. Down : Thermal recovery at 2.38 and 3.28 eV and for 2 and 4 eV in the inset. Points represent the annealed absorption in % of the total RIA.

REFERENCES

[1] S. Girard *et al.*, IEEE Trans. Nucl.Sci., **60**, p2015, 2013
[2] D. L. Griscom, J. Non-Cryst. Sol., **357**, p1945, 2011
[3] A. Morana *et al.*, Optical Mat. Express, **3**, p1769, 2013
[4] F. Mady *et al.*, Optics lett., **35**, p3541, 2010
[5] H. Hosono *et al.*, Nucl. Instr. Meth. B, **91**, p395,1994
[6] S.Girard *et al.*, IEEE Trans. Nucl. Sci., **54**, p2426, 2007